Primary Repair of Tetralogy of Fallot in Infancy Using Profound Hypothermia with Circulatory Arrest and Limited Cardiopulmonary Bypass:

A Comparison with Conventional Two Stage Management

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IT HAS BECOME conventional, in most centers, to palliate severely affected infants with the tetralogy of Fallot by performing either a Waterston or a Blalock anastomosis, and to delay second stage intracardiac repair until 4 or 5 years of age. It is claimed that such two-stage management provides superior results to primary intracardiac repair,[11] which has been associated with a high hospital mortality and a high morbidity rate when undertaken in this age group.

The recent advent of safer intraoperative and postoperative technics in the infant group,[4,10] led us to question the superiority of two-stage repair and to embark upon a program of primary repair in the tetralogy, regardless of both the age of the patient and the morphology of the right ventricular outflow tract obstruction. This report presents the results of this method of management in the first 2 years of life and compares these results with those obtained employing two-stage management. Only patients with cyanotic tetralogy of Fallot are included; those with pulmonary atresia and large ventricular septal defect (pseudo-truncus) or with pulmonary stenosis and double outlet right ventricle and its variants are excluded.

Period A (1960–1969)

In this decade a palliative operation was performed in severely cyanotic tetralogy infants presenting in the first 2 years of life (Table 1). For completeness, three infants aged 3, 5 and 7 months who had a Waterston anastomosis performed in 1970 and 1972 (Period B), because it was inconvenient to arrange emergency intracardiac repair, have been included in this analysis.

In earlier years palliation consisted of a Blalock or Potts anastomosis and occasionally, when these failed, a blind pulmonary valvotomy (Brock procedure). In later years a Waterston anastomosis was preferred in the first year of life. Seven of the 44 infants required a second palliative procedure because the first was ineffective and two of these failed to survive. The mortality was 50% below 4 months of age, but thereafter fell sharply to approximately 10%. Our material does not show any lessening of shunt mortality in infants in recent, compared with earlier years, although others have found this to be so.[11,12]

In addition to this significant hospital mortality, there is considerable morbidity from palliative surgery after hospital discharge and an occasional late death. Incomplete relief of cyanosis, failure to thrive and recurrent respiratory infections have been common. Three patients developed a cerebral abscess which was a cause of late death in two and represents a late mortality of 6%.

To this already formidable list must be added the mortality of second-stage repair. Thirty-three of the 44

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TABLE 1. *Primary Palliative Procedure Performed in Tetralogy* (1960–1969)

Age range (months	Blalock		Waterston		Potts		Brock		Total	
	No.	Deaths	No.	Deaths	No.	Deaths	No.	Deaths	No.	Deaths
0–3	3	2	8	4	1	0	—	—	12	6
4–7	5	0	5	0	1	1	1*	0	12	1
8–11	4	1	2	0	—	—	—	—	6	1
12–23	11	1	3	0	—	—	—	—	14	1
Totals	23	4	18	4	2	1	1	0	44	9

* This procedure was ineffective but was followed by a satisfactory Waterston shunt. Two other Brock valvotomies were performed following unsatisfactory shunts at 1 and 4 months of age but both infants died. These deaths are listed as occurring following the primary palliative procedure.

infants survived palliation and 24 of these have now undergone second-stage repair with two deaths. Both these children, operated upon at 4 years of age, had absence or occlusion of the left pulmonary artery, a complcation which carries a high risk.[8] In the absence of this complication the risk of second-stage rapair is currently little different from primary repair in experienced hands and approximates 3% to 5%.[1,8,11]

Summarizing this information, the data indicate that when an infant with tetralogy demands surgical relief before the age of 4 months, the chances of survival with two-stage management are less than 50%. When palliation is not performed until 4 months or later, however, survival increases to approximately 85%. When the analysis includes all infants palliated under 2 years of age, survival beyond second-stage repair approximates 70% to 75% but is clearly dependent on the number of infants palliated in very early life.

Period B (1970–1973)

Commencing in February 1970, 24 tetralogy infants with severe progressive cyanosis or cyanotic spells have undergone primary intracardiac repair rather than a palliative shunt procedure (Table 2). An additional 13-month-old child with a previous Waterston anastomosis is also included (Case 19) because the shunt was per-

TABLE 2. *Results of Primary Repair of Tetralogy in the First Two Years of Life (Feb. 1970 to March 1973)*

Case No.	Age	Wt (Kg.)	Circulatory arrest Temp (°C)	Circulatory arrest Time (min)	Outflow patch	Systolic pressures (mm. Hg) PA/RV/Ao	Respiratory Support	Isoprenaline infusion
1	4 wks	3.7	20	45	No	13/50/90	IPPB	Yes
2	5 wks	3.2	21	60	Yes*	20/30/50	IPPB	Yes
3	6 wks	5.4	19	60	Yes*	15/29/52	IPPB	Yes (died)
4	2 mo	4.5	19	45	No	20/34/60	CPAP	No
5	2 mo	3.6	22	62	Yes	22/30/50	IPPB	Yes
6	3 mo	5.1	22	56	Yes*	14/23/52	Nil	No
7	3 mo	4.0	18	67	Homograft*	10/20/61	IPPB	Yes
8	3 mo	5.0	18	67	Yes*	—/27/45	CPAP	Yes
9	4 mo	5.6	20	42	No	29/32/76	IPPB	Yes
10	7 mo	7.8	22	50	No	11/55/70	Nil	No
11	7 mo	5.6	20	59	No	18/23/70	Nil	No
12	8 mo	6.7	19	44	No	19/29/95	CPAP	Yes
13	9 mo	7.7	20	47	Yes*	50/65/90	Nil	No
14	9 mo	7.6	22	49	No	23/23/80	Nil	Yes
15	9 mo	10.8	19	55	No	22/40/95	Nil	No
16	11 mo	8.0	23	62	Yes*	25/38/70	Nil	No
17	11 mo	7.5	19	38	No	—/26/110	CPAP	Yes
18	12 mo	7.8	22	43	No	23/30/100	Nil	No
19	13 mo	8.1	19	54	No±	32/37/90	CPAP	Yes
20	13 mo	8.3	18	52	No	22/45/95	Nil	No
21	13 mo	8.9	24	43	No	13/20/67	Nil	No
22	16 mo	8.5	20	59	Yes*	25/65/90	Nil	No
23	16 mo	8.0	20	49	Yes	22/35/82	IPPB	Yes
24	18 mo	6.5	22	46	No	19/19/52	Nil	No
25	21 mo	9.9	23	44	No	14/20/65	Nil	No

PA-pulmonary artery; RV-right ventricle; Ao-aorta; IPPB-intermittent positive pressure breathing; CPAP-continuous positive airway pressure.

* Severe hypoplasia outflow tract with PA diameter $\frac{1}{3}$ or less that of the aorta.

± Previous Waterston anastomosis at 5 months of age.

formed during the period under review and because she was readmitted in a comatosed state with severe cyanosis and underwent emergency intracarciac repair. No infant was refused operation because of age or unfavorable morphologic findings. The youngest child was 4 weeks old and had had a repair of esophageal atresia soon after birth. Eight patients were under 4 months of age, 10 were aged 4 to 12 months and seven were aged 13 to 21 months. Weights ranged from 3.2 to 10.8 Kg. and most were within the normal range for age (Fig. 1). The frequency of severe hypoplasia of the right ventricular outflow and pulmonary trunk was far higher in infants under 4 months of age (5 of 8) than in those over this age (3 of 17) (Figs. 1 & 2).

Technic of Repair

Intracardiac repair was performed using deep hypothermia with circulatory arrest and limited cardiopulmonary bypass.[2] Deep hypothermia was induced using cardiopulmonary bypass alone in one instance. In the remainder the temperature was lowered by surface cooling to approximately 25 C before exposing the heart, cooling was then completed by a short period of cold perfusion which averaged 7 minutes. Circulatory arrest was established by occluding both cavae and the aorta at a nasopharyngeal temperature between 18 C and 24 C and the intracardiac repair performed. The arrest time varied from 38 to 67 minutes. In recent cases surface cooling has been continued to a temperature of 22 C using a plastic water bed and anterior ice bags and the temperature lowered with perfusion to 18 C to 19 C prior to arrest (Fig. 3).

The right ventricle was opened with a short transverse incision unless the angiocardiogram and preliminary dissection indicated severe outflow tract hypoplasia, when a vertical incision was made. Infundibular obstruction was relieved by mobilizing and excising the septal and parietal bands of the crista and the pulmonary valve was examined from below. Any leaflet fusion was divided and distal leaflet tethering released. Assessment of the need for enlargement of the outflow region by an anterior pericardial gusset was made at this time. A gusset was inserted whenever there was important residual narrowing and thickening of the pulmonary ring and pulmonary valve leaflets, particularly when these thickened structures narrowed the orifice to less than one half of the aortic root diameter. The patch always extended across the pulmonary valve ring and, when the bifurcation of the pulmonary trunk was also narrowed, into one or both of its branches. The elliptical patch had a maximum width of 5 to 7 mm and enlarged the outflow to no more than 75% aortic root diameter.

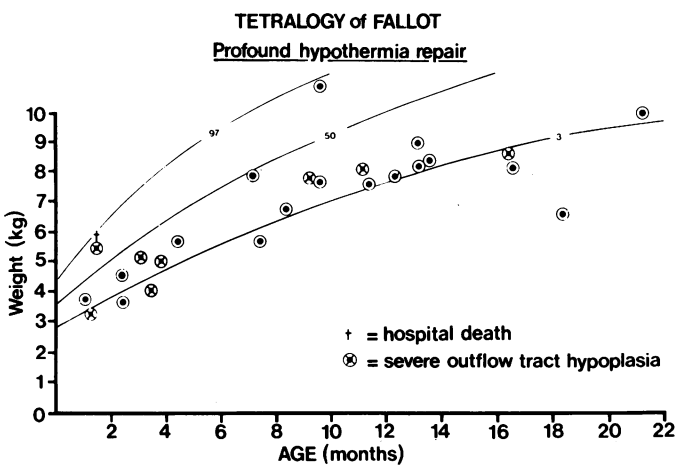

FIG. 1. Age and weight in the 25 infants undergoing intracardiac repair. The curved percentile weight lines have been averaged for boys and girls from the data supplied by the Children's Medical Center, Boston.

An outflow patch was required in six of the eight infants under 4 months of age (in Case 7, with virtual absence of pulmonary leaflet tissue, a valved aortic homograft was used instead), but in only four of the 17 (25%) over this age (Table 2).

The ventricular septal defect was closed with a woven teflon patch using interrupted sutures. The atrial septum was exposed routinely as the size and nature of any interatrial communication was not established preoperatively.

With the heart closed and emptied of air, rapid rewarming to 35 C was obtained by a further period of cardiopulmonary bypass, which averaged 22 minutes. Right and left atrial pressure lines and ventricular pacing wires were positioned prior to chest closure.

Results

There was one hospital death 36 hours postoperatively in a 6-week-old infant (Case 3) due to progressive severe cyanosis. At necropsy no pulmonary cause for this was demonstrated and the repair was intact. This infant was one of the eight with severe hypoplasia of the outflow tract. The right ventricular/aortic systolic pressure ratio at the end of repair was low in this infant (Table 2) and was above 70% in only three instances (Cases 10, 13, 22).

The postoperative course in most of the 24 surviving patients was uneventful, despite the fact that all had been severely incapacitated. Assisted ventilation or continuous positive airway pressure[14] were used for 12 to 24 hours in seven of the eight infants up to 3 months of age, but in only five of the 17 over this age (Table 2). Tracheostomy was not required. Significant respiratory complications occurred in only two of the survivors, in one related to respiratory infection and in the other to inhalation of vomit 48 hours postoperatively. A continuous Isoprenaline infusion was required in 12 of the 25 for periods of 18 to 48 hours (Table 2) but in only one of the

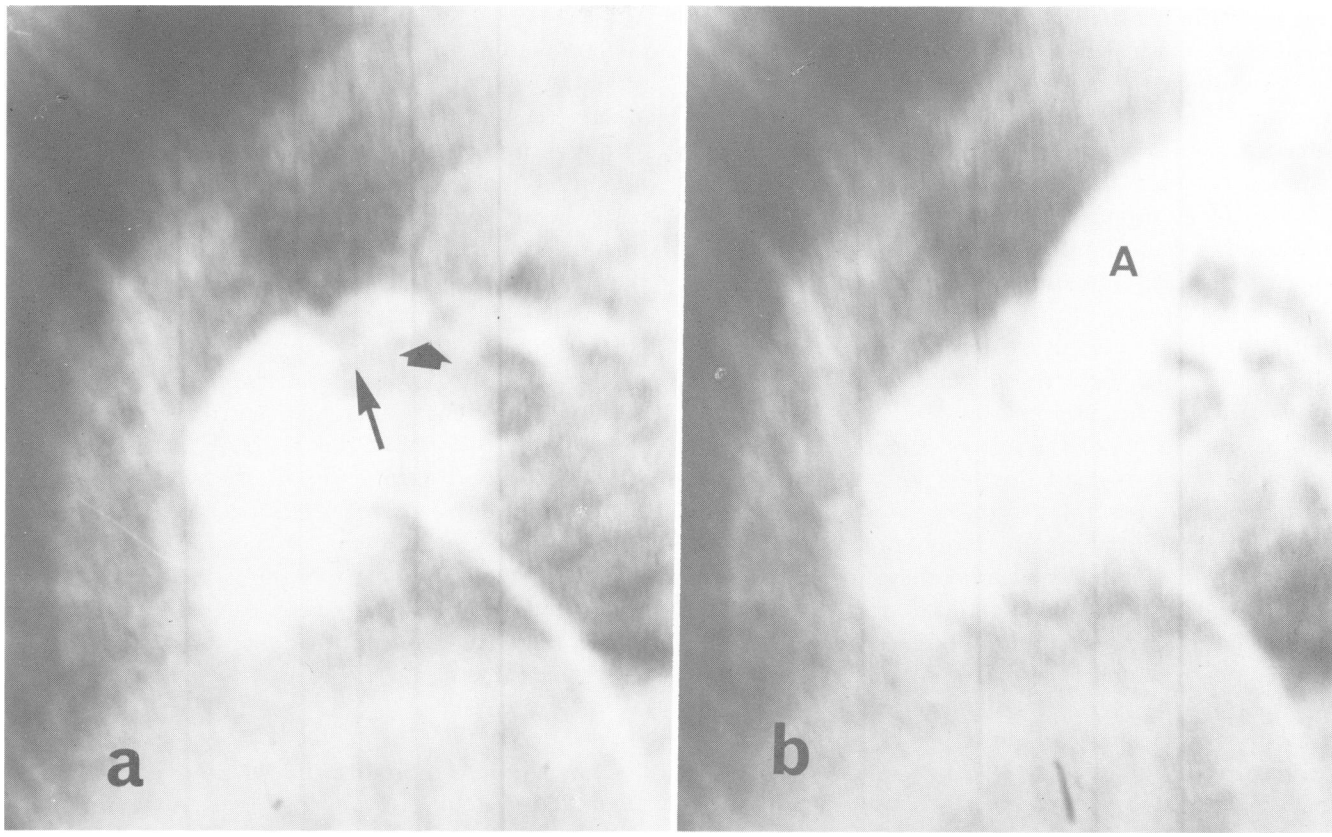

FIG. 2. Two cineangiogram frames in diastole from Case 8 which demonstrate severe outflow tract hypoplasia. The thin arrow marks the site of maximal infundibular obstruction and the thick arrow the small pulmonary ring and thickened pulmonary leaflets. The pulmonary trunk is less than ⅓ the diameter of the aorta (A). At operation a pericardial patch was inserted from distal right ventricle into the first few mm of the left pulmonary artery. The main pulmonary artery had a diameter of 6 mm and the branch origins 4 mm.

24 survivors was there serious concern about a low cardiac output. Fat necrosis of the anterior abdomen and chest, due to the ice bags used for cooling, was recorded in six infants and was the cause of persistent fever. Complete heart block was present in Cases 8 and 14 after warding but disappeared on the eighth postoperative day. One patient had an isolated rightsided seizure 30 hours postoperatively but no others have shown evidence of cerebral irritation or cerebral damage.

On subsequent clinical assessment the cardiac status of all survivors has been good without evidence of a residual ventricular septal defect and in the three patients who have been recatheterized to date, the data are confirmatory. Patient 13 died 6 months postoperatively of epidemic gastroenteritis. At necropsy the repair of the heart was satisfactory and the lung vasculature was normal.

Discussion

The argument in favor of primary intracardiac repair in infancy rather than conventional two-stage management, centers chiefly around the current mortality of

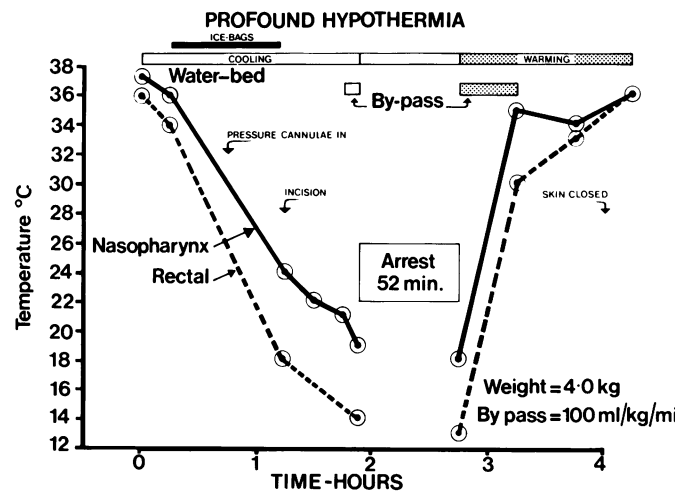

FIG. 3. Graphic representation of operative events in a 4 Kg. tetralogy infant using the current method of surface cooling with a water bed rather than a cooling blanket. Total anesthetic time was 4 hours with delay occurring only between the completion of insertion of the pressure lines and the sternotomy incision. This delay corresponds roughly to the time interval that would have been occuppied by cardiopulmonary bypass had cooling been entirely by this means.

shunt palliation in this age group, for the late mortality following shunt surgery is relatively low, at 6% in our series and 4% in the Mayo Clinic series;[11] and the risk of repair is not significantly increased by a previous Waterston or Blalock shunt. Analysis of five series[5, 6, 7,9,12] published between 1964 and 1971 encompassing a total of 381 tetralogy infants palliated in the first year of life, reveals a hospital mortality varying from 12.5% to 30% and averaging 22%. In the two reports where there is an analysis of the age at operation in months[9,12] the data confirm that the risk is far greater in the first few months of life. Combining these results with our own, it would appear that the hospital mortality of shunt palliation when performed under the age of 4 months is between 35% and 50% and beyond this age falls to 10% or less. This latter figure is similar to that quoted as the current risk of palliation in infancy by Puga *et al.*[11] possibly because their series includes a prepondence of infants over 3 months of age. Both our data and those of Starr *et al.*[13] suggest that the high mortality in the early months of life is due to the frequency of severe hypoplasia of the outflow tract in this age group. Accordingly, before the policy of primary intracardiac repair can be considered clearly superior to two-stage management, it must be shown that primary repair is also applicable in these tiny infants with severe disease. Our results suggest this is so, although the numbers are still too small to be confident of it.

At this early stage in the development of safe technics for intracardiac repair in infancy, it is natural that there should be debate as to the best technic. We have preferred profound hypothemia with circulatory arrest because it provides superb operating conditions and therefore avoids surgical error and because we have found no evidence that, when properly conducted, it is associated with cerebral damage. In this connection, psychometric testing is now being conducted in those infants operated upon under profound hypothemia in 1969 and 1970. The results do not show any important deviation from normal. It is possible that extracorporeal circulation at normothermia or mild hypothermia may prove a satisfactory alternative technic. However the recent report from Starr *et al.*[13] using extracorporeal circulation for tetralogy repair in infancy, includes only one child under 4 months of age and excludes those with severe hypoplasia of the outflow tract.

Any discussion of this subject is incomplete without considering the morbidity associated with the two alternative methods of management. Following shunt palliation in infancy a significant number of babies are limited by cyanosis, poor weight gain and recurrent respiratory infections and a second palliative operation may be required. The need for constant skilled medical supervision and the parental anxiety associated with a second major operation some time in the future, are both unsatisfactory features. However, if primary repair is used in all instances, the morbidity must be minimal and no greater than when repair is delayed until an older age. In our series and that of Starr *et al.*[13] there has been no important morbidity, in particular no permanent complete heart block and no recognizable residual ventricular septal defect. It must be conceded, however, that tetralogy repair is an exacting operation and the technic must be perfected in older children before it is transferred to the infant group. Finally, can additional morbidity be expected because early repair leads to a higher incidence of right ventricular outflow tract patching? We doubt if this is so. Although an outflow patch was used frequently in the youngest patients, these symptoms occurred early because of the severity of their disease. From what is known of the progressive nature of the pulmonary stenosis at valve and subvalve level it is probable that early repair will lessen rather than increase the incidence of outflow patching in less severe cases.

Summary

The hospital mortality in 44 infants with severe cyanotic tetralogy of Fallot palliated in the first 2 years of life was 20%, the late mortality 6% and the mortality at second-stage repair 8%. The chance of survival beyond second-stage repair was less than 50% when the infant required palliation under 4 months of age and approximately 85% when palliation was undertaken between 4 and 24 months of age.

In contrast, the hospital mortality of primary intracardiac repair in 25 infants under two years of age performed using profound hypothermia with circulatory arrest and limited cardiopulmonary bypass, was 4%. There was no significant morbidity although one infant died late from unrelated disease. No infant was excluded on the grounds of age or unfavorable morphology. Eight infants had severe hypoplasia of the right ventricular outflow tract and eight were under four months of age.

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